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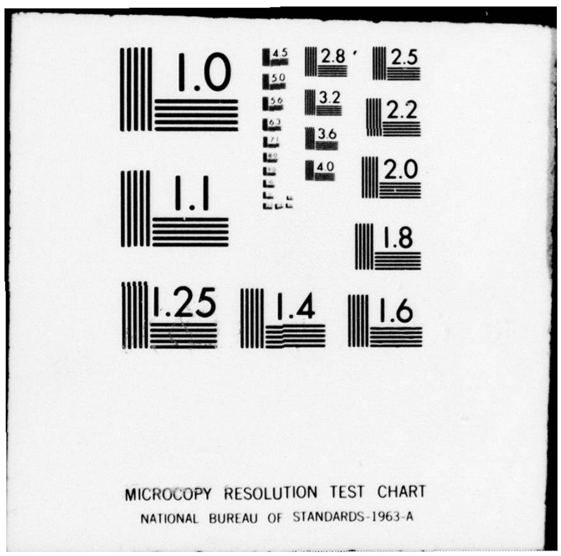
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SOUTH AUSTRALIA

TECHNICAL REPORT

WSRL-0012-TR

UPPER ATMOSPHERE RESEARCH AT WRE - A REVIEW

K.H. LLOYD

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10 K.H. Lloyd

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Upper atmosphere research using sounding rockets was supported at Weapons Research Establishment by the Australian Government from 1960 until 1976. This paper reviews the upper atmosphere project as it was carried out by the three Groups involved. The rocket vehicles are described, together with the experiments carried in them including details of the techniques used. The most significant scientific discoveries obtained from the data are presented and discussed.

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1. INTRODUCTION

Research into the upper atmosphere at the Weapons Research Establishment* commenced independently in two Groups, at about the same time, c.1960, and in both cases the research was associated with development of rockets for use at Woomera. The two Groups undertaking the research, Flight Projects and Upper Atmosphere Physics, concentrated their efforts on different regions and different techniques. In 1968 the two groups were amalgamated into Upper Atmosphere Research Group, which continued until termination of the project in 1976.

This review of upper atmospheric research outlines the achievements of these three groups, and the methods and techniques used. The development and evolution of the aims of the project, which mirrored increasing knowledge of the upper atmosphere with time, suggest that the project be treated chronologically. This suggestion has been followed.

Because of the diverse nature of the experiments, and the variety of sounding rockets which were used, this information has been drawn up in tabular form for ease of reference. In Table 1 are listed all the rocket vehicles used to conduct upper atmospheric soundings, Table 2 gives details of the Australian designed motors for these vehicles, and Table 3 contains a summary of all the types of upper atmosphere research experiments which have been conducted. Appendix I is a bibliography of all internal publications reporting the results of these experiments and Appendix II lists the external publications. In both appendices the references have been split into sections, divided according to experimental methods, as discussed in the text. Where a paper is interdisciplinary, it has been listed under the section which is most important in the paper.

2. FLIGHT PROJECTS GROUP, SYSTEMS ANALYSIS DIVISION

2.1 Introduction

Flight Projects Group commenced in 1960 to develop rockets from boosts, surplus to the U.K. defence program, for firing at Woomera as upper atmosphere research vehicles. In the early days, partly in order to test which configurations were preferable, and partly because of the variety and limited number of any one boost motor, several vehicles were produced of which only a few were fired. The designs finally settled on were HAD (High Altitude Density) and HAT (High Altitude Temperature), with a limited number of Long Tom vehicles for large or multiple experiments. A photograph of HAD on the launcher is shown in figure 1. All the rockets were basically the same design: two stage with solid propellant. As will be discussed later, stocks of U.K. boosts were limited, and as early as 1965 the first moves were made to design and produce a series of suitable Australian motors.

2.2 Experiments

The earliest experiment carried by a Flight Projects Group sounding rocket was a micrometeorite detector, built by the Australian National University, but subsequent experiments were either developed totally within Flight Projects or jointly with the Physics Department of the University of Adelaide.

* The four Wings comprising the Weapons Research Establishment became four Laboratories of the Defence Science and Technology Organisation (collectively known as the Defence Research Centre Salisbury) on 3 April 1978.

2.2.1 Falling sphere

The first of the Flight Projects Group experiments was the falling sphere. The sphere was two metres in diameter and made of Mylar - a metallised plastic sheet. It was packed into the head of the rocket, and, at apogee, the nose cone was released by a compressed air system, expelling the sphere into the low density atmosphere, whereupon it inflated by residual air pressure. The pressure was then increased by the rupture of a canister of isopentane attached to the inside of the sphere. The isopentane evaporated, providing a pressure sufficient to maintain sphere inflation down to an altitude of 40 km.

A photograph of an inflated sphere is given in figure 2. Because of its very light construction it was able to give data at higher altitudes than the equivalent system being developed elsewhere. In order to give a measureable drag on the sphere by the extremely low density atmosphere at 80 km it was necessary to develop construction techniques which were both strong and light. This was successfully accomplished.

The descent of the sphere was tracked by radar and analysis of the air drag over its trajectory enabled the atmospheric wind, density and temperature profiles from 80 km to 40 km altitude to be determined. This analysis required accurate data on the drag coefficient of a sphere over a wide range of Reynolds and Mach numbers. These data had to be compiled from several sources. In order to determine density and temperature as well as atmospheric wind, it had to be assumed that the wind vector was horizontal. Theoretical arguments, and the consistency of the data, indicate that this is a good approximation. A typical temperature profile obtained from falling sphere data is given in figure 3. At the time, data such as these were scarce, and such profiles were valuable in constructing models of the upper atmosphere. For example, the U.S. Standard Atmosphere 1966 over this altitude range uses these data.

All the falling sphere firings were conducted at evening twilight. This was done initially so that, should the radars have trouble in acquiring the sphere, visual acquisition was also possible. However, even when radar acquisition was reliable, this firing time was used, as it enabled long term variations in the parameters, uncontaminated by diurnal effects, to be determined. The results obtained for long term variations will be discussed later.

2.2.2 Drop sonde

As a complement to the falling sphere, a method to measure the atmospheric temperature and pressure directly by a parachute borne sonde was developed. The sonde, which contained the experiment, was ejected from the rocket head at apogee. This could not be above 75 km, for at such altitudes the air is too tenuous to successfully deploy the parachute. The sonde measured temperature by monitoring the resistance of a small bead thermistor mounted on a yoke, extended after release. Pressure was measured by determining the impedance of the air in a chamber open to the ambient atmosphere, a method developed within WRE. Later, the pressure probe was replaced by 2 channel ultra-violet detector, filtered to pass 50 nm wide bands centred at 250 nm and 300 nm. At these wave-lengths ozone is weakly and strongly absorbing respectively, so that the ozone density from 70 km to 30 km could be calculated from the observed increase in attenuation of solar flux due to absorption by atmospheric ozone as the sonde descended.

Figure 4 shows a photograph of an ozone sonde. The entire package, complete with batteries, weighed only 800 gm. The design of the parachute, below which the ozone sonde was suspended, required careful

consideration to provide lift at the tenuous density encountered. The sonde was suspended from the parachute by a 10 m riser line. This increased the stability of the system, and also reduced the chances of screening of the sun from the detector by the parachute. Typical profiles of ozone density from 55 to 30 km determined using the ozone sonde are given in figure 5: the profiles below 30 km were measured by Mast Model Electrochemical sondes, which were carried by Meteorological balloons, released to coincide with the rocket firings.

In parallel with the experimental development of the ozone sonde, theoretical studies were conducted on the effect of hydrogenous compounds on the ozone profile. It was discovered that water vapour had a profound influence on the equilibrium distribution of ozone, and subsequent computer models of ozone in the upper atmosphere have always included water vapour.

2.2.3 Collaboration with the University of Adelaide

The third experimental method of upper atmospheric research used in Flight Projects Group involved the Physics Department of the University of Adelaide. They had been measuring the absorption cross-section of molecular oxygen, and other gases, in the laboratory and this gave motivation to measure the oxygen profile by observing the extinction of solar radiation by absorption spectrometers. The measurements were done in the vacuum ultra-violet and X-ray wavelength region, so special ionisation gauge detectors were designed and built. Eventually a whole series of such detectors was developed to measure different atmospheric constituents. In a similar experiment, the ozone profile was determined at night by observing the full moon. At apogee these detectors gave measurements from above the atmosphere of absolute solar and lunar fluxes, allowing calculation of solar temperature at the 'solar temperature minimum' and of lunar ultra- violet reflectivity.

Figure 6 shows a typical payload carrying X-ray ionisation detectors.

2.3 WRESAT

In 1967, the United States of America conducted a series of experiments at Woomera using Redstone rockets, and offered one of the rockets to launch a satellite for Australia. Flight Projects Group was chosen as the prime group in the design and development of the satellite; it carried ionisation gauges developed by the University of Adelaide, these being the most suitable experiments of those which had been developed. The short time scale between the offer of the vehicle and the launching, one year, did not allow time to develop any new experiments. The profiles of atomic oxygen, molecular oxygen, nitrogen and atomic hydrogen ("geocoronal hydrogen") were measured by occultation of the sun behind the Earth.

The satellite was launched successfully, and continued to telemeter data for 12 days, until the batteries were exhausted. Figure 7 shows a photograph of the satellite. The most valuable data were gained from the X-ray ionisation chambers measuring oxygen absorption. They showed that a "ledge" in the oxygen profile is a common feature of the lower thermosphere.

2.4 Carnarvon

In order to determine the spatial variation in the parameters being measured by the falling sphere technique, it was decided to conduct firings from Carnarvon, Western Australia, where a radar suitable for tracking the sphere was located. Three successful campaigns were conducted, manned entirely by Flight Projects personnel. The first two campaigns concentrated on comparing data from spheres released simultaneously at Woomera and at Carnarvon. They showed the existence of large horizontal variations in

atmosphere parameters, so that "weather patterns" occur in the mesosphere, as they do at lower levels. The third campaign launched 10 rockets in one 24 hour period. The data collected from these firings provided a base for the study of diurnal variations of wind, temperature and density in the mesosphere.

Finally, the Carnarvon campaign demonstrated that it is possible to conduct successful firings of upper atmosphere research rockets from mobile launchers using very basic facilities (in this case, a single high quality radar).

3. UPPER ATMOSPHERE PHYSICS GROUP, AERODYNAMICS DIVISION

3.1 Introduction

While Flight Projects Group was conducting its upper atmosphere research experiments, Research Vehicles Group in Aerodynamics Division was assisting the United Kingdom Space Research Council in the preparation of Skylark sounding rockets for firing at Woomera. Among the experiments carried by the Skylark rockets was a series of experiments designed to determine the temperature and wind profiles of the atmosphere by measuring the time taken for the shock wave from exploding grenades, ejected from the rocket, to reach the ground. It was discovered that these grenades produced long lived glowing clouds when exploded above 90 km.

Instrumentation Group of A.D. had the capability of building photometers and camera systems to record the behaviour of these clouds, and it was decided in 1961 to start a program of observations of the glow clouds from which winds could be deduced from their drift, and diffusion from their expansion. This research was initially carried out by personnel in Instrumentation and Theoretical Supersonics Groups. Eventually, in 1967, these efforts were amalgamated into a single group called Upper Atmosphere Physics.

3.2 Experiments

3.2.1 Aluminised grenade explosions

When the possibilities of glow cloud observations were realised by University College London, the initiators of the grenade experiments, the altitude range of the grenade releases was extended upwards. University College invited A.D. to co-ordinate in the observations, and this formed the start of a close collaboration between the two groups.

The main line of research lay in the determination of atmospheric density from the diffusive expansion of the gas cloud produced by the grenade explosion. A few seconds after the detonation, the grenade cloud is in equilibrium with the atmosphere, and its subsequent rate of expansion is a function of atmospheric density. The diffusive growth of a grenade cloud is shown in figure 8, in which is plotted the Gaussian radius of the cloud as a function of time. At that time, diffusion of vapour clouds was the only satisfactory method to measure density in this difficult region of the thermosphere, and the data obtained formed an invaluable basis for comparison with other methods, such as mass spectrometry which initially had many teething troubles.

It was subsequently discovered, by spectroscopic observations, that, at night, the glow was produced by chemiluminescent reactions between aluminium monoxide, AlO, and atmospheric atomic oxygen; but when illuminated by sunlight, there was a dominant contribution from sunlight resonantly scattered by AlO. The relative intensities of the bands in the resonance spectrum enabled the ambient atmospheric temperature to be determined. This is done by comparing the intensity distribution

across the observed spectrum with that of theoretical spectra. The theoretical spectra were calculated from the known photo-excitation rates of $A\ell O$ in sunlight, assuming the ground state of $A\ell O$ is in thermodynamic equilibrium with the ambient atmosphere. Figure 9 compares an observed spectrum with theoretical spectra for different assumed ambient temperatures. It can be seen that temperature can be determined to $\pm 50^{\circ}$ K. By releasing a succession of grenades along the rocket trajectory, a complete profile of the atmospheric temperature can be measured. This method is one of the few available for measuring atmospheric temperature at these altitudes.

In addition to confirming the sensitivity of upper atmospheric temperature to the emission of X-rays and EUV radiation from the sun (monitored by 10.7 cm decametric flux), it was found that on occasions there existed a subsidiary minimum in the temperature profile at 200 km altitude. No satisfactory explanation has been advanced for the latter phenomenon.

3.2.2 Chemical releases

The occurrence of chemiluminescent reactions aroused the interest of the then Chemistry and Physics Division at WRE who realised that herein lay a powerful tool to study gas phase chemical reactions in a wall-free environment. It was decided to start a chemical release program for the dual purpose of studying suitable chemiluminescent reactions and of measuring parameters of the upper atmosphere. For this purpose a rocket, Aero High, was built, from which grenades doped with chemicals of possible interest were released. Other chemicals were also released, including nitrogen dioxide, and trimethylaluminium (TMA), both of which, in principle, enabled an estimate of the atomic oxygen profile to be determined. However, the data from these releases showed that the chemical reaction scheme was more complicated than had been thought. In addition, it was found that the released chemicals clustered into dimers, thereby further complicating the issue. Although these deductions were valuable from the viewpoint of chemical kinetics, they made estimates of atomic oxygen density very unreliable. However, release of TMA did prove valuable for other reasons, which will be discussed later.

4. UPPER ATMOSPHERE RESEARCH GROUP, AEROSPACE DIVISION

4.1 Introduction

In 1968, a WRE re-organisation united the two groups conducting rocket research in the upper atmosphere, Flight Projects and Upper Atmosphere Physics, into a single group. This group, named Upper Atmosphere Research, was located in the renamed Aerospace Division.

4.2 Rockets and related technology

As has been mentioned, the supply of boost motors from surplus U.K. missiles was limited, so, starting in Flight Projects Group, a program of designing motors to be produced locally was initiated. The accent on the design was functional simplicity. It also gave the opportunity for development within Propulsion and Marine Physics Division of cast composite rocket propellants, and for the Explosives Factory at Maribyrnong to gain experience in design and production of rocket motors with these propellants.

Between 1968 and 1976 four rockets were developed, called Kookaburra, Cockatoo, Lorikeet and Corella; there were several Mark types, indicating different motor sizes and propellants. Specifications of these rockets are

given in Table 2. Figure 10 shows the Kookaburra rocket, which is the smallest of the four.

Requirements for cheap and reliable timers for ignition of the second stage, and for the release of grenades, lithium etc., accurate to 1 s, initiated a successful program of development of rolled lead tube delay burners in P.M.D.. This Division also developed lithium vapour dispensors for releasing trails of atomic lithium from rockets.

4.3 Experiments

The experiments conducted by U.A.R. Group evolved from those of its constituent groups. In 1969, an Interdepartmental Committee, constituted to determine the future of, inter alia, the upper atmosphere research project, heard presentations from all Sections involved direcly or indirectly in the project. Their findings were that upper atmosphere research should continue, but that it should be slanted more toward ionospheric observations, with possible defence relevance.

First, however, we will discuss the investigations into the neutral upper atmosphere, which were continued and updated as dictated by advancing technology and increasing knowledge of the atmosphere.

4.3.1 Falling sphere

The falling sphere experiment was repeated as nearly as possible at monthly intervals. Because of the large number of years over which the firings were conducted, they became a prime source of data for international standard reference atmospheres. The data had the additional benefit of being the only significant data from the Southern hemisphere, and were used on many occasions as prime data in modelling global upper atmospheric behaviour. An example of the use of the data is shown in figure 11 which plots the power spectrum of the zonal wind. It was calculated from all falling sphere data using the standard methods of spectral analysis. The spectrum shows well defined annual and semi-annual components. Also evident is a component at a period of approximately 26 months, which has previously only been detected at the equator. It is called "quasibiennial" and is thought to have a strong influence on the long term (i.e. several year) climatic variations. All this information on the strength of the annual, semi-annual and quasibiennial waves as a function of altitude is extremely useful in trying to unravel the vagaries of the weather. This work is in its infancy, as it is only in recent years that sufficient data for its inception have been available.

4.3.2 Ozone sonde

The ozone and temperature sonde firings continued. They were always co-ordinated with low altitude observations from a Meteorological balloon carrying a Mast model ozone detector, and total ozone measurements using a Dobson Spectrophotometer. In addition, this was the era in which the first satellites were being put into orbit to measure the atmospheric temperature profile by remote sensing. The accuracy of this technique was still unknown, and there was a need for in-situ rocket measurements to confirm the satellite data. The temperature sonde was able to furnish the required "ground truths", and on several occasions the sonde was fired to coincide with the passage overhead of Nimbus and Tiros satellites.

Sufficient data were now accumulating to make a start on unravelling the chemical kinetics of the mesosphere. So a mathematical model was developed to use with the observations in a study of the reactions involving ozone in the upper atmosphere. One of the aims of these

studies was to ascertain which processes were important for maintenance of the ozone layer, and how sensitive the layer may be to man-made pollutants, in particular to the gaseous oxides of nitrogen, collectively denoted by NO_x. An example of the outcome of this work is given in figure 12, which compares observed values of NO_x density with values calculated from assumed reaction schemes involving ozone. The agreement is good, and indicates the validity of the modelling scheme. Studies of this kind are the first steps to understanding the possible effects of man-made pollutants on the Earth's weather systems.

4.3.3 Composition measurements

Several additional experiments were devised to extend the atmospheric composition studies in the region between 70 and 120 km altitude. One vehicle carried an upwards pointing telescope with chopped phase-sensitive detection. This instrument was sensitive to near-infrared radiation in the emission bands of the OH radical which is an important participant in the complicated photochemical reactions occurring above 80 km. Emission profiles of the airglow resulting from the chemical activity were measured, in the zenith direction, up to 122 km altitude.

Co-operative work with the University of Adelaide continued. While the series of measurements of daytime molecular oxygen and day and night-time ozone densities was extended, other experiments were devised and flown to complement this basic work. Development of miniature ionisation chambers operating with internal gas-gain, together with very sensitive high-speed amplifiers, enabled measurements to be done with narrow-field telescopes at night-time intensities. In the centre of figure 13, which shows a typical payload, can be seen the large collecting mirror of one of the telescopes. Below are ozone absorption detectors and the aspect sensor.

Scans of the night sky at the hydrogen Lyman alpha wavelength in the vacuum ultra-violet led to a unique determination of the atomic hydrogen density between 75 and 120 km. Figure 14 shows how the measurements compare with some previous theoretical predictions. The method also allowed night-time molecular oxygen measurements to be done from small sounding rockets rather than the large stabilized rockets or satellites normally required.

Measurements with the telescope permitted the extension of lunar surface reflectivity measurements down to the wavelength of hydrogen Lyman alpha, showing that the vacuum ultra-violet reflectivity is higher than mid-ultra-violet trends had suggested.

The Physics Department of the University of Adelaide extended the range of their X-ray detectors to give total atmosphere densities in the range covered by their molecular oxygen measurements. They also designed and flew small mass spectrometers to measure neutral and positive ion species in the atomic mass unit range from 10 to 40 a.m.u. This provides an independent source of information for comparison with the continuing measurements based on absorption photometry. Finally, airglow measurements were extended into the near-infra-red region in an experiment to use the effects of ozone on hydroxyl emission as a means of extending the upper limit of the ozone density profiles measurements above the absorption experiment altitudes.

4.3.4 Chemical releases

The program of releasing vapour into the upper atmosphere to measure winds was continued. Above 80 km atmospheric motions consist predominantly of three sets of waves, which are: tides, whose periods are

diurnal and semidiurnal; internal gravity waves covering a spectrum from a few minutes to a few hours; and turbulence, which overlaps the lower end of the gravity wave spectrum. A good indication of these waves is given in figure 15 which shows the development of a lithium trail released from a Cockatoo rocket. The large spiral shape is caused by tides; the small scale structure by turbulence. Note the abrupt disappearance of turbulence at about 105 km, which is in itself a subject of great interest.

In order to observe the development of tides it was necessary to extend the period of observation from twilight into daytime. This was done by building a sensitive scanning detector which was able to discriminate a lithium trail against the bright day sky. Figure 16 is a photograph of the instrument. Typical results obtained from it are shown in figure 17, which gives the observations on a lithium trail, plotted by computer from data on magnetic tape.

Close co-operation also continued with the University College London, at whose Skylark firings releasing TMA and lithium, U.A.R. Group were essential observers. The experiments became more sophisticated, and extended from simple determination of the density, temperature, wind and turbulence profiles of the neutral atmosphere, to a complete coverage of all the relevant parameters necessary to observe the deduce the dynamic inter-relation of ionised and neutral species. The results from these experiments will be discussed later.

4.3.5 Ionospheric experiments

As mentioned earlier, the Interdepartmental Committee of 1969 recommended that more emphasis should be placed on ionospheric research. U.A.R. Group had already taken a step in this direction with the installation down range at Woomera of a radio frequency partial reflection system, operating at 2 MHz. This experiment, which determined ionospheric drifts, was conducted by the Physics Department of the University of Adelaide. In addition, two rocket borne ionospheric experiments were developed and flown by U.A.R. Group. One, a swept frequency plasma probe, measured the electron density by observing resonances in the ionospheric impedance. Later, a nose tip Langmuir probe was added, which gave small scale details in the electron density profile. A photograph of the payload showing the plasma impedance probe and Langmuir probe is given in figure 18. Figure 19 shows telemetered output from the plasma impedance probe. The changes in amplitude and phase of the detected signal, which are functions of ionospheric density, are clearly seen. Figure 20 shows the electron density profile determined from a Langmuir probe. Except for a systematic shift at lower altitudes, which is produced by outgassing from the rocket second stage, the upleg and downleg profiles agree very well.

The plasma resonance and Langmuir probes fitted naturally into the chemical release program. The altitude range over which the release was made is one in which there are important electrodynamic effects involving the ionosphere. Attention was concentrated upon two of these - sporadic E and the Sq current system. The former is an intense layer of ionisation usually formed by wind shear. In a co-operative venture with University College London, the Max-Planck Institute Munich, and the Mullard Space Science Laboratory London, in which electron density, atmospheric electric field and wind shear were all measured simultaneously, the influence of the electric field on the formation of a stable layer of sporadic E was demonstrated for the first time.

The Sq current system also depends on the atmospheric electric field. Observed values of this parameter, which were determined from data on drift of a cloud of barium ions released from a grenade, have shown that the theory of this phenomenon is still inadequate.

In order to gain maximum benefit from these studies into the movement of ionisation in the lower thermosphere, an ionosonde and a magnetometer were installed at the down range site at Woomera. The former gives continuous information on the ionosphere, paricularly on sporadic E layers; the latter provides data from which the direction and strength of the ionospheric currents can be inferred. These results were combined with data from the rockets to gain a better understanding of ionospheric transport processes.

A further rocket borne ionospheric experiment was developed in conjunction with the Physics Department of the University of Adelaide. It was a differential absorption payload, making use of the 2 MHz transmitter used for the ionospheric drift experiment. By measuring the difference in absorption by the ionosphere of the transmitted Ordinary and Extraordinary waves, the electron desnity profile can be determined.

5. CONCLUSION

It is difficult to provide a conclusion to an open-ended research project such as this. The very nature of a "non-mission-oriented" project precludes a cut and dry conclusion. Nevertheless we list here what we regard as some of the more significant, interesting and useful results of the upper atmosphere program:

(a) The long term synoptic falling sphere data provided a basis for reference atmospheres, and gave detailed information of annual, semi-annual and quasi-biennial variations.

(b) The ozone sonde provided input data to modelling chemical kinetics in the mesosphere and below. This provides estimates of the densities of NO_x and other species which relate to the contamination of the atmosphere by mankind.

(c) Theoretical calculations modelling the reactions of ozone in the upper atmosphere gave the first evidence of the importance of water vapour on the ozone density profile.

(d) Determination of thermospheric temperature from observations of the spectrum of AlO vapour clouds showed the occurrence of a subsidiary temperature minimum at 200 km altitude. As yet, no satisfactory explanation exists to account for this phenomenon.

(e) Release of trails of TMA and lithium vapour gave fresh evidence and insights into the problems of turbulence in the atmosphere. Reasons for the existence of the turbopause have been advanced, but the matter is not yet settled.

(f) A specially built scanner to detect lithium vapour trails in daytime provided evidence for the behaviour of atmospheric tides in the upper atmosphere throughout the day.

(g) A plasma resonance probe was flown during a period when travelling ionospheric disturbance activity appeared on ionograms taken at Woomera. This gave direct measurements on the ionospheric layering which produces this phenomena.

(h) Simultaneous rocket borne measurements of wind, electric field and electron density through a sporadic E ionospheric layer provided direct evidence of the electric field stabilising such a layer.

(i) Measurement of the airglow emission profile at the Lyman alpha wavelength gave a unique determination of the atomic hydrogen density profile from 75 to 120 km.

(j) Observations, at apogee, of the sun and the moon in the vacuum ultraviolet enabled calculation of the solar U.V. 'temperature minimum', and of lunar U.V. reflectivity.

In addition, the Upper Atmosphere Research program provided stimulus and impetus to the following areas of defence relevance:

(a) Rocket vehicle research.

(b) Rocket propellant development.

(c) Successful production of pyrotechnic delays.

(d) Development of burners to release chemicals.

(e) Technological awareness of measurement of winds by tracking falling spheres by radar.

(f) Entry into the fields of electronics and telemetry in a hostile environment.

(g) Exercise of range capabilities.

ACKNOWLEDGEMENTS

The task of a reviewer is no more than to gather together the work of other researchers, in some kind of order, under one cover. The credit for the work reported here goes to all those who were involved in the Upper Atmosphere Research project; their enthusiasm enabled results to be achieved which were remarkable in view of the small size of the Groups engaged on the project. I am particularly grateful to B.C. Bowers, C.H. Low, G.G. O'Connor, P.H.O. Pearson and N.V. Sissons for their assistance in compiling this review.

APPENDIX I

PUBLICATIONS ON UPPER ATMOSPHERE RESEARCH (INTERNAL)

No.	Author	Title
I.1 Vehicle design		
1	Rofe, B.	"Australian Sounding Rocket Experiments". WRE Tech. Note SAD 127, July 1963.
2	Johnson, S.G.	"A Lamp Projection Mechanism for Use as a Tracking Aid in High Altitude Research Vehicles". WRE Tech. Memo SAD 132, July 1963.
3	Cartmel, J.A.B. and Hunt, B.G.	"Some Initial Studies for Lightweight Meteorological Rockets". WRE Tech. Memo SAD 148, September 1963.
4	Simpson, G.J.	"Preliminary Aerodynamic Tests in the Development of an Upper Atmosphere Parachute". WRE Tech. Memo, PAD 177, November 1964.
5	Simpson, G.J. and Secombe, G.H.	"Operational Testing of a High Altitude Parachute System". WRE Tech. Note, PAD 106, July 1965.
6	Simpson, G.J.	"Performance Trials of High Altitude Meteorological Parachutes". WRE Tech. Note, SAD 169, January 1968.
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8	Simpson, G.J.	"Assessment of the Skua Meteorological Parachute Performance from Trials at Woomera". WRE Tech. Memo, HSA 190, June 1969.
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26	O'Connor, G.G.	"Lyman Alpha Radiation in the Night-time Mesopause and Lower Thermosphere. I: Transport of Radiation in the Absorber-Scatterer Mixture". WRE Tech. Note, (WR&D) 1360, April 1975.
27	O'Connor, G.G.	"Lyman Alpha Radiation in the Night-time Mesopause and Lower Thermosphere. II: Measurement of Atomic Hydrogen and Molecular Oxygen Densities in the Night-time Atmosphere". WRE Tech. Note, (WR&D) 1361, April 1975.
28	Sissons, N.V.	"Feasibility of Measuring Nitrogen Dioxide Concentrations Below 50 km by Means of Differential Absorption in the Spectral Region Around 4400Å". WRE Tech. Note, (WR&D) 1689, To be published.
29	Low, C.H. and Lloyd, K.H.	"Upper atmosphere Research Bibliography of Contaminant Release Experiments. Part 3." WRE Tech. Memo 1788 (W) March 1977.

APPENDIX II

PUBLICATIONS ON UPPER ATMOSPHERE RESEARCH (EXTERNAL)

No.	Author	Title
II.1 Description of equipment		
1	Low, C.H. and Groves, J.R.V.	"Photomultiplier Fatigue". Elec. Eng., 38, 44, 1966.
II.2 Experiments using the falling sphere		
1	Pearson, P.H.O.	"Seasonal Variations of Density, Temperature and Pressure Between 40 and 90 km, Woomera, South Australia, March 1964 - March 1965". J. Atmos. Terr. Phys., 28, 1057, 1966.
2	Pearson, P.H.O.	"Annual Variations of Density, Temperature and Wind Between 30 and 97 km at Woomera Shortly After Dusk, 1962 - 1972". COSPAR Space Research XIV, 1974.
3	Vincent, R.A. Stubbs, T.J. Pearson, P.H.O. Lloyd, K.H. and Low, C.H.	"A comparison of partial reflection drifts with winds determined by rocket techniques". J. Atmos. Terr. Phys. 39, 813, 1977.
II.3 Research on ozone in the upper atmosphere		
1	Hunt, B.G.	"The need for a Modified Photochemical Theory of the Ozonosphere". J. Atmos. Sci., 23, 1, 1966.
2	Hunt, B.G.	"Photochemistry of Ozone in a Moist Atmosphere". J. Geophys. Res., 71, 5, 1966.
3	Carver, J.H. Horton, B.H. and Burger, F.G.	"Nocturnal Ozone Distribution in the Upper Atmosphere". J. Geophys. Res., 71, 17, 1966.
4	Carver, J.H. Horton, B.H. and Burger, F.G.	"Rocket Determination of the Night Ozone Distribution and the Lunar Ultraviolet Flux". In Space Research VII, Ed. R.L. Rose-Smith, 1967.
5	Bowers, B.C.	"A Discussion of an Apparent Relationship Between Ozone Densities above 25 km and Geomagnetic Activity". Planet. Space Sci., 19, 1583, 1971.
6	Sissons, N.V.	"On the Estimation of Stratospheric NO_2 Concentrations from Parachute Dropsonde Measurements of Ozone". Proc. IAMAP/IAPSO First Special Assembly, Melbourne, 1974.

No.	Author	Title
II.4 Experiments using chemical seeding techniques		
1	Johnson, E.R. and Lloyd, K.H.	"Determination of Diffusion Coefficients from Observations on Grenade Glow Clouds". Aust. J. Phys. 16, 491, 1963.
2	Sheppard, L.M. and Lloyd, K.H.	"Atmospheric Density and the Diffusion of Grenade Glow Clouds". Planet. Space Sci., 12, 317, 1964.
3	Lloyd, K.H. and Sheppard, L.M.	"Atmospheric Structure in the Lower Thermosphere". Planet. Space Sci., 13, 1313, 1965.
4	Lloyd, K.H. and Sheppard, L.M.	"Atmospheric Structure at 130 - 200 km Altitude from Observations on Grenade Glow Clouds During 1962 - 63". Aust. J. Phys., 19, 323, 1966.
5	Low, C.H.	"Atmospheric Temperature Measurement above 100 km from AlO Spectra". Planet. Space Sci., 15, 199, 1967.
6	Johnson, E.R. Lloyd, K.H. Low, C.H. and Sheppard, L.M.	"The Radiant Output of Grenade Glow Clouds in the Lower Thermosphere". Aust. J. Phys., 20, 683, 1967.
7	Lloyd, K.H. and Golomb, D.	"Observations on the Release of a Cloud of Barium Atoms and Ions in the Upper Atmosphere". AFCRL Environmental Research Paper, No. 268, 1967.
8	Low, C.H. Hind, A.D. Rees, D. and et al.	"Neutral Wind Measurement During Daytime in the Thermosphere". Nature, 240, 32, 1972.
9	Rees, D. Roper, R. Lloyd, K.H. and Low, C.H.	"Determination of the Structure of the Atmosphere between 90 and 250 km by means of Contaminant Releases at Woomera, May 1968". Phil. Trans. Roy. Soc., 271, 631, 1972.
10	Lloyd, K.H. Low, C.H. McAvaney, B. Rees, D. and Roper, R.	"Thermospheric Observations Combining Chemical Seeding and Ground Based Techniques. I: Winds, Turbulence and the Parameters of the Neutral Atmosphere". Planet. Space Sci., 20, 761, 1972.
11	Rees, D. Haerendel, G. Felgate, D. Lloyd, K.H. and Low, C.H.	"Thermospheric Observations Combining Chemical Seeding and Ground Based Techniques. II: Ionospheric Drift and the Sq Current System". Planet. Space Sci., 21, 1237, 1973.
12	Lloyd, K.H. Low, C.H. and Vincent, R.	"Turbulence Billows and Gravity Waves in a High Shear Region of the Upper Atmosphere". Planet. Space Sci., 21, 653, 1973.

No.	Author	Title
13	Hind, A.D. and Lloyd, K.H.	"A Determination of the Daytime Thermospheric Wind Profile by Observing a Lithium Trail with a Field of View Scanner". Aust. J. Phys. <u>27</u>, 401, 1974.
14	Low, C.H. and Hind, A.D.	"Daytime Winds in the Lower Thermosphere". Proc. IAMAP/IAPSO First Special Assembly, Melbourne 1974.

II.5 Ionospheric experiments

No.	Author	Title
1	Lloyd, K.H. and Haerendel, G.	"Numerical Modelling of the Drift and Deformation of Ionospheric Plasma Clouds and of their Interaction J. Geophys. Res., <u>78</u>, 7389, 1973.
2	Rees, D. Lloyd, K.H. et al	"Investigations of Mid-latitude Ionospheric Currents by Combined Rocket Techniques". Space Research XIII, Ed. M. Rycroft and S. Runcorn, Akademie Verlag, Berlin, 1973.
3	Rees, D. Dorling, E.B. Lloyd, K.H. and Low, C.H.	"The role of Neutral Winds and Ionospheric Electric Field in Forming Stable Sporadic E Layers". Planet. Space Sci., <u>24</u>, 475, 1976.

II.6 Background scientific research

No.	Author	Title
1	Lloyd, K.H.	"Theoretical Models for the Brightness of Contaminant Glow Clouds in the Upper Atmosphere". Aust. J. Phys., <u>18</u>, 349, 1965.
2	Lloyd, K.H.	"Absorption of a Grazing Ray Calculated by Ray Tracing". Planet, Space Sci., <u>17</u>, 1683, 1969.
3	Lloyd, K.H.	"The Earth's Shadow in the Lithium 6707A Line". J. Atmos. Terr. Phys. <u>35</u>, 1529, 1973.
4	Lloyd, K.H.	"Investigations into the Nature of the Turbopause". Proc. IAMAP/IAPSO First Special Assembly, Melbourne, 1974.

II.7 General and other experiments

No.	Author	Title
1	Lawrence, T.F.C.	"Rocket Sounding Vehicles, Their Characteristics and use". Lecture to Inst. of Eng. (Aust), 1959.
2	Bird, D.A.H.	"The Australian Sounding Rockets Long Tom and Aeolus". J. Roy. Aero. Soc., <u>64</u>, 593, 1960.
3	Sheppard, L.M.	"The Temperature at 120 km Altitude in April - May 1965". Aust. J. Phys., <u>21</u>, 939, 1968.

No.	Author	Title
4	Rofe, B. and Twiss, P.M.	"Australian Sounding Rocket Experiments, complementing Satellite Firings". United Nations Conference on the Exploration and Peaceful uses of Outer Space, Vienna, August 1968.
5	Carver, J.H. Edwards, P.J. Gough, P.L. Gregor, A.G. Rofe, B. and Johnson, S.G.	"Solar Absorption Photometry and the Determination of Atmospheric Composition". J. Atmos. Terr. Phys. 31, 4, 1969.
6	Bowers, B.C.	"Galactic Lyman Alpha and the Interstellar Shock Wave". Nature, 228, 1182, 1970.
7	Carver, J.H. Horton, B.H. Ilyas, M. and O'Connor, G.G.	"The Ultraviolet Reflectivity of the Moon". The Moon, 9, 295, 1974.
8	Carver, J.H. Horton, B.H. Ilyas, M. and O'Connor, G.G.	"Rocket Measurements of High Altitude Molecular Oxygen". Proc. IAMAP/IAPSO First Special Assembly, Melbourne, 1974.
9	O'Connor, G.G.	"Lyman Alpha Radiation in the Night-time Mesopause and Lower Thermosphere - I: Transport of Radiation in the Absorber-scatterer Mixture". J. Atmos. Terr. Phys. 38, 377, 1976.
10	O'Connor, G.G.	"Lyman Alpha Radiation in the Night-time Mesopause and Lower Thermosphere - II: Measurements of Atomic Hydrogen and Molecular Oxygen densities in the Night-time Atmosphere". J. Atmos. Terr. Phys. 38, 383, 1976.

TABLE 1. ROCKET VEHICLES USED IN UPPER ATMOSPHERE RESEARCH

Vehicle name	No. fired	1st stage	2nd stage	Payload		Apogee alt. (km)
				Length (cm)	Weight (kg)	
Long Tom	6	3 Mayfly	Mayfly	178	65	130
Aeolus	3	Lap Star	Mayfly	178	65	76
HAT	58	2 Demon	Lap Star	102	18	75
HAD	116	Gosling	Lap Star	89	16	120
Aero High	19	Gosling	Vela	175	52	200
Kookaburra 1	84	Lupus 1	Musca	52	4.5	75
Cockatoo 1	49	Gosling 1	Lupus 1	89	16	130
Kookaburra 2	27	Lupus 2	Musca	57	4.5	128
Cockatoo 2	4	Gosling 1	Lupus 2	102	21	145
Lorikeet 1	2	Dorado 1	Lupus 1	102	21	75
Cockatoo 4	16	Gosling 4	Lupus 1	35	16	135
Cockatoo 3	9	Gosling 4	Lupus 2	102	21	145
Kookaburra 3	4	Lupus 3	Musca	57	4.5	140
Lorikeet 2	6	Dorado 1	Lupus 3	102	21	140
Corella 1	2	Gosling 4	Dorado	147	45	200

TABLE 2. AUSTRALIAN DESIGNED MOTORS USED FOR UPPER ATMOSPHERE SOUNDING ROCKETS

Motor	Diameter (cm)	Length+ (cm)	Weight: Charge (kg)	Weight: Total+ (kg)	Total Impulse (Ns)	Burning Time (sec)
Musca	8.9	128	8.4	13.6	19100	3.90
Lupus 1	12.7	164	18.2	32.0	37800	5.15
Lupus 2	12.7	164	19.7	33.5	46200	5.2
Lupus 3	12.7	196	25.4	41.0	60900	4.90
Dorado 1	18.0	293	74.0	114.6	172000	5.15

+ Including venturi

TABLE 3. ROCKET BORNE UPPER ATMOSPHERE RESEARCH EXPERIMENTS

Experiment	Vehicle	Parameters measured	Altitude range
Falling sphere	HAD Cockatoo Kookaburra	Atmospheric density, pressure, temperature and wind	40-80 km
Ozone sonde	HAT Kookaburra	Temperature, ozone (earlier, pressure)	30-70 km
UV and X-ray absorption cells	HAD Cockatoo Lorikeet	Atomic oxygen, molecular oxygen, nitrogen	50 km up
Lyman alpha detector	Cockatoo	Atomic hydrogen, geocoronal hydrogen	80 km up
Hydroxyl airglow detector	Cockatoo	Hydroxyl (OH) radical	80 km up
Silver strips	Cockatoo	Atomic oxygen	80 km up
Mass spectrometer	Lorikeet	All neutral species (10 to 40 a.m.u.)	50 km up
Aluminised grenade glow clouds	Aero High Corella	Density, wind (twilight and night) Temperature (twilight only) Atomic oxygen (night only)	85 km up
T.M.A. trail release	Aero High	Denisty, wind turbulence (twilight and night) Temperature (twilight only) Atomic oxygen (night only)	85 km up
Lithium vapour trails	Cockatoo Corella	Winds (day and twilight) Turbulence (twilight only)	85 km up
Swept frequency probe	Cockatoo Lorikeet	Absolute electron density	90 km up
Langmuir probe	Cockatoo Lorikeet	Small scale structure of electron density	70 km up
Differential absorption	Kookaburra	Absolute electron density	60-90 km

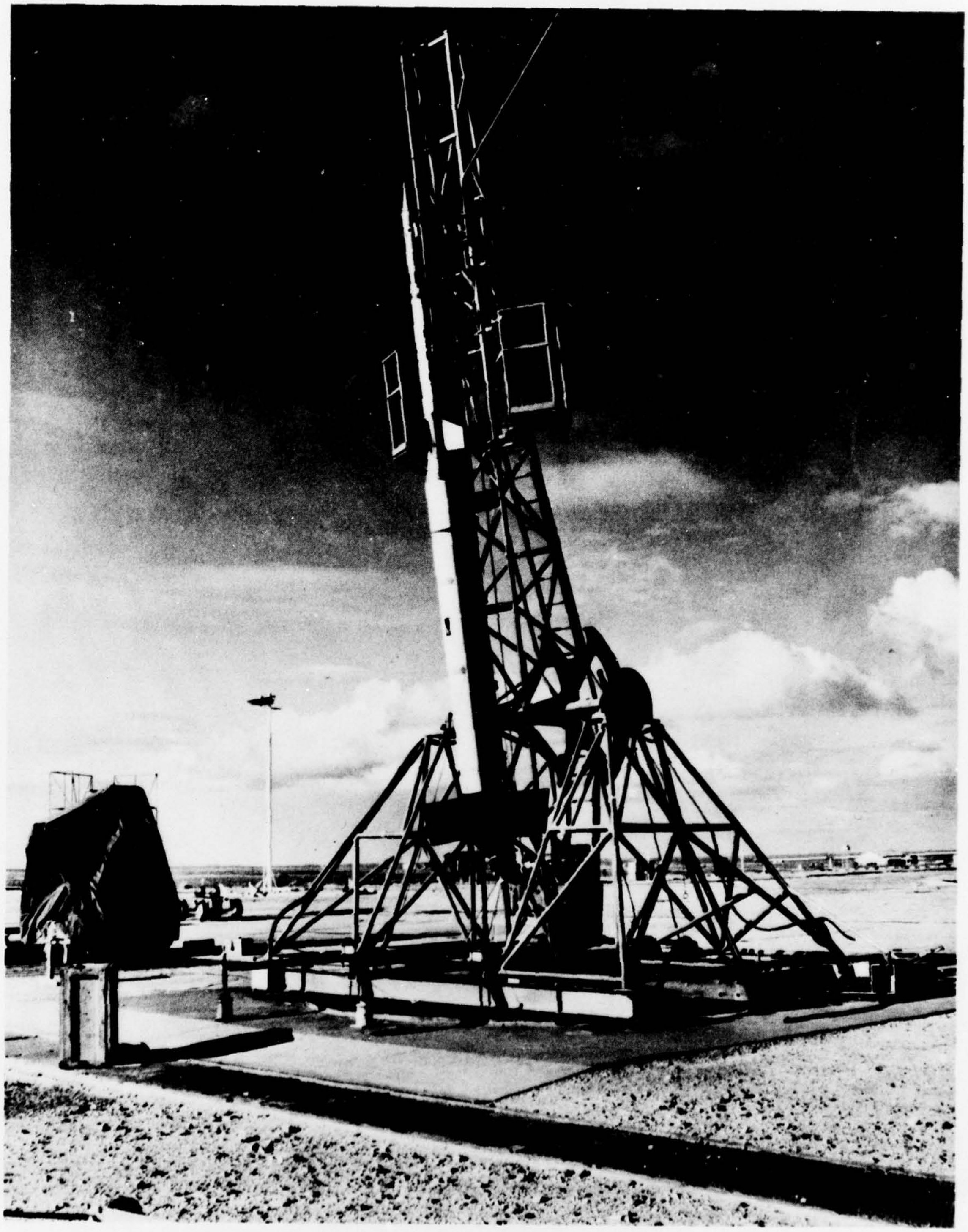


Figure 1. HAD on the launcher

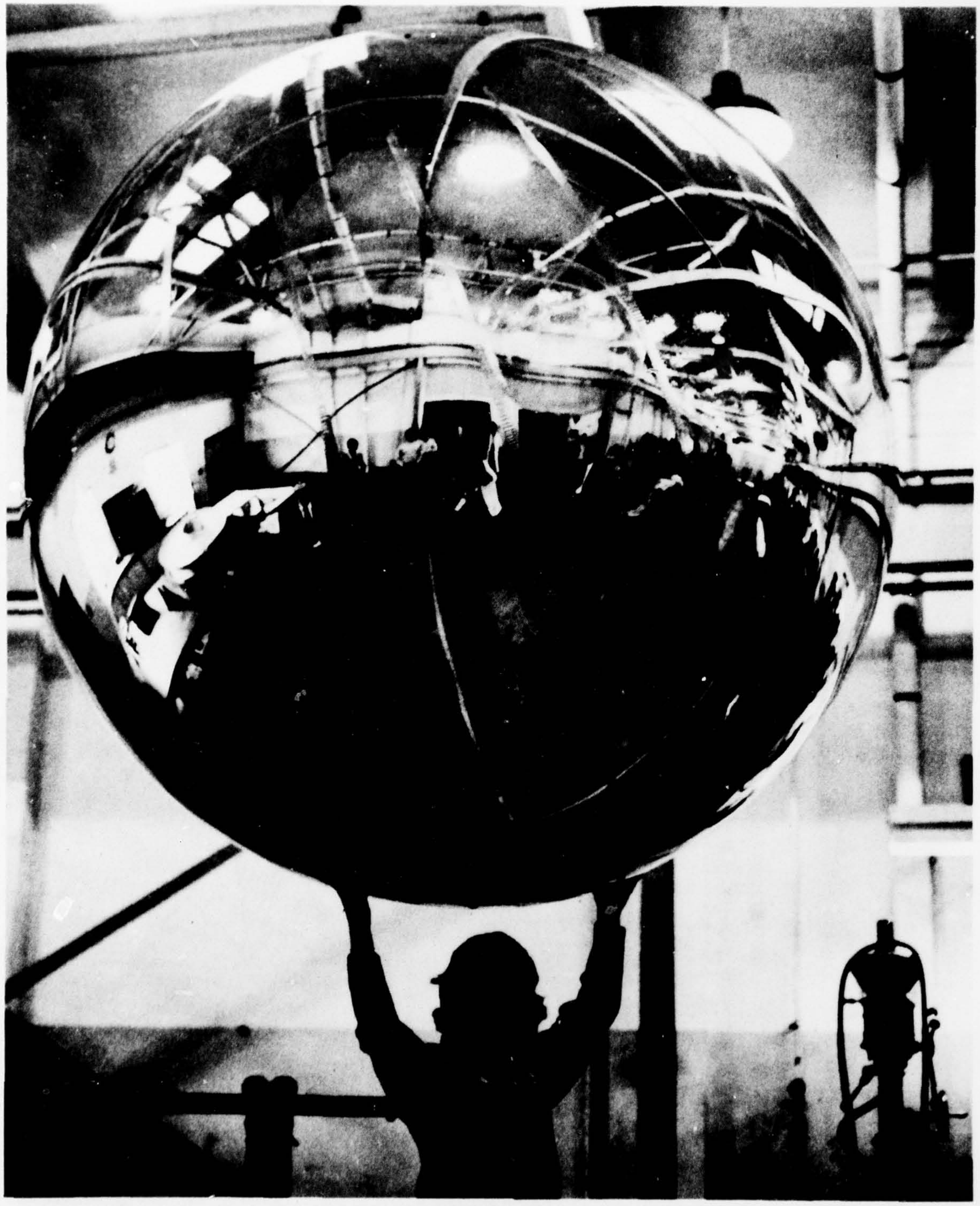


Figure 2. Inflated falling sphere

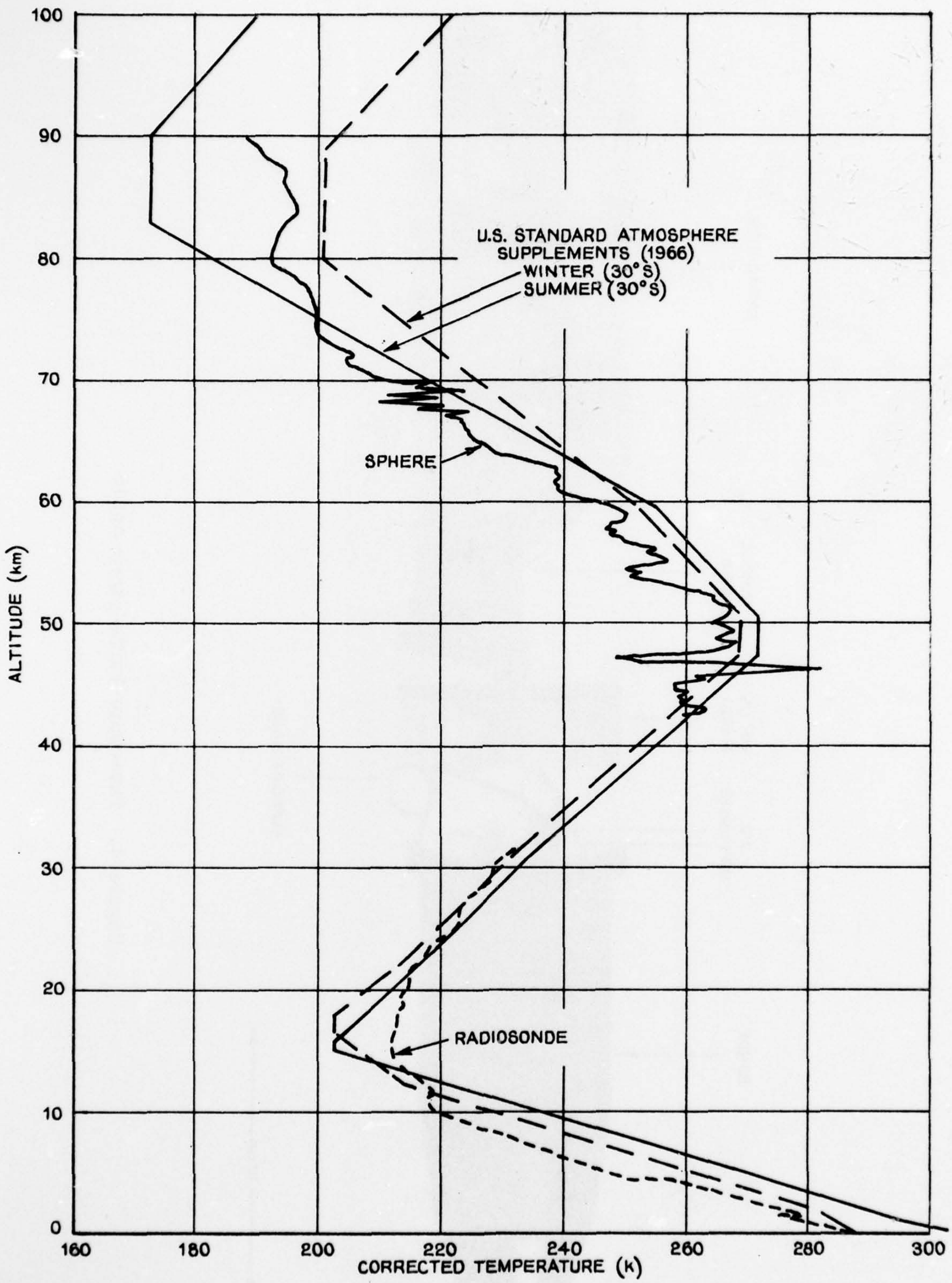


Figure 3. Atmospheric temperature profile from falling sphere data

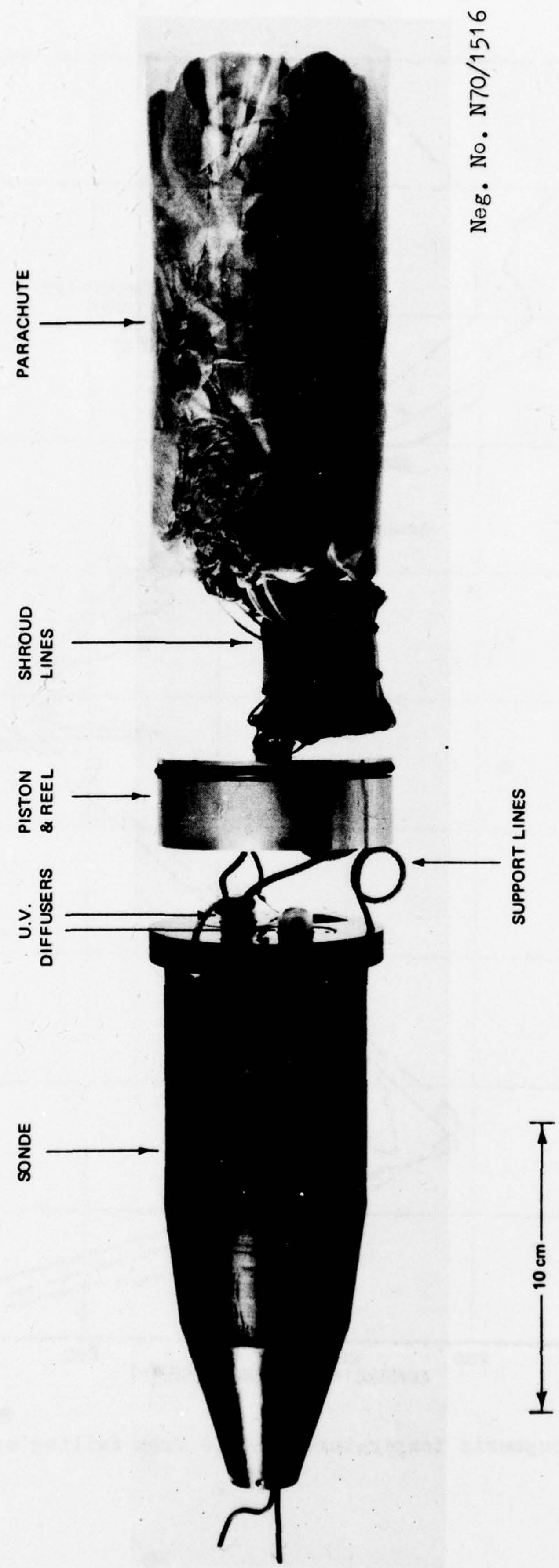


Figure 4. Parachute borne ozone sonde

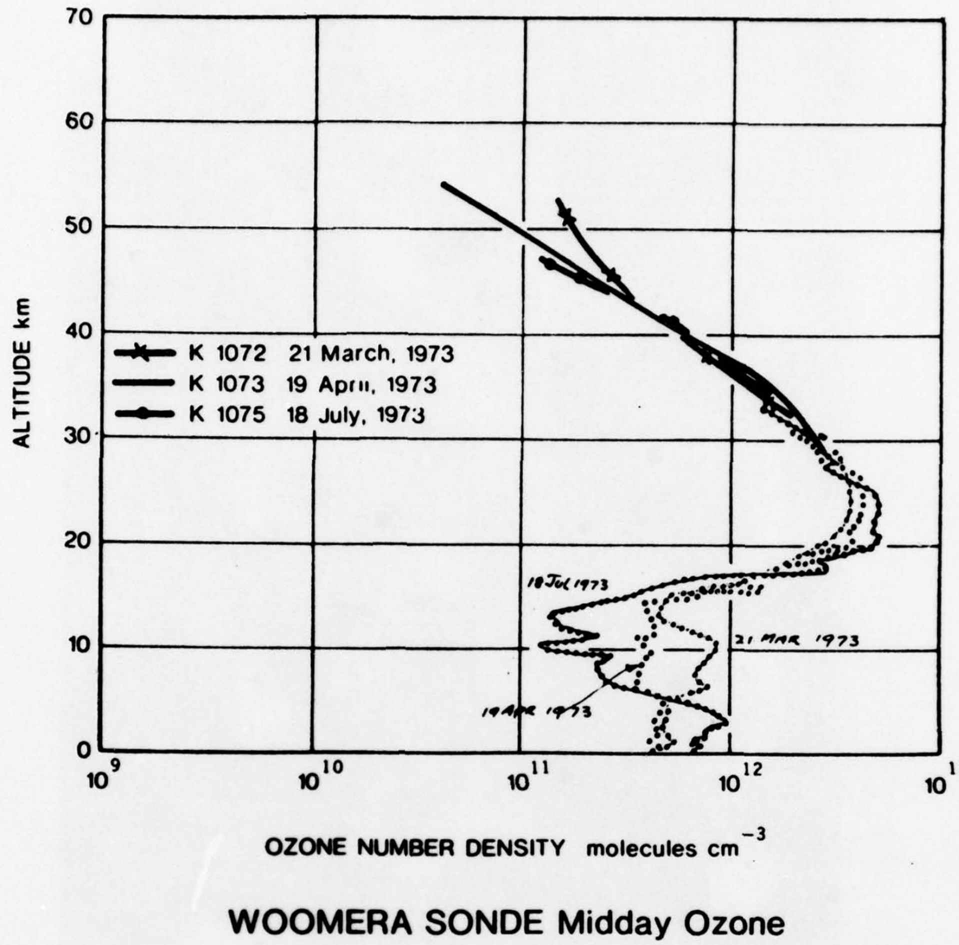


Figure 5. Ozone profile determined from ozone sonde data

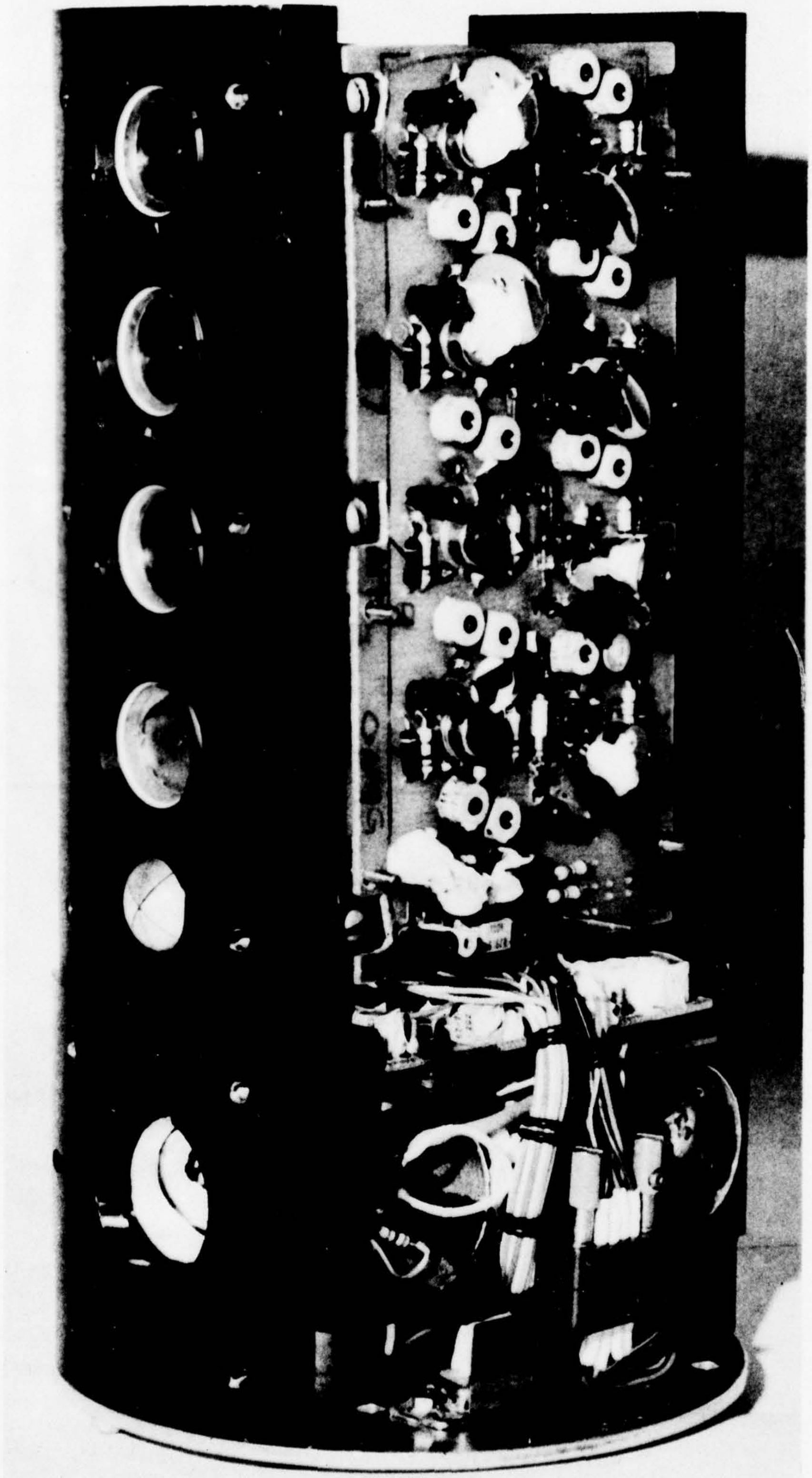


Figure 6. Payload carrying X-ray ionosation detectors

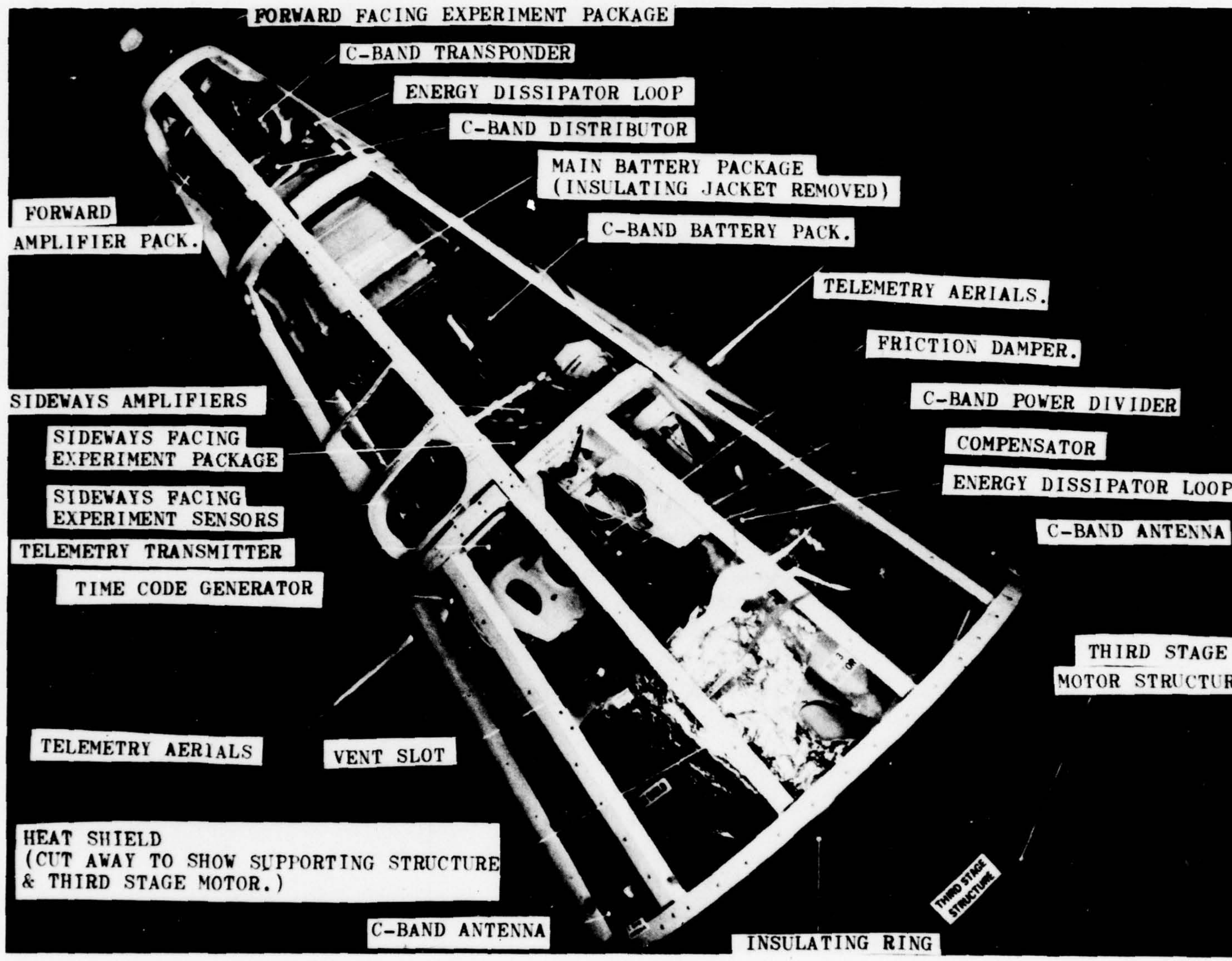


Figure 7. WRE satellite (WRESAT)

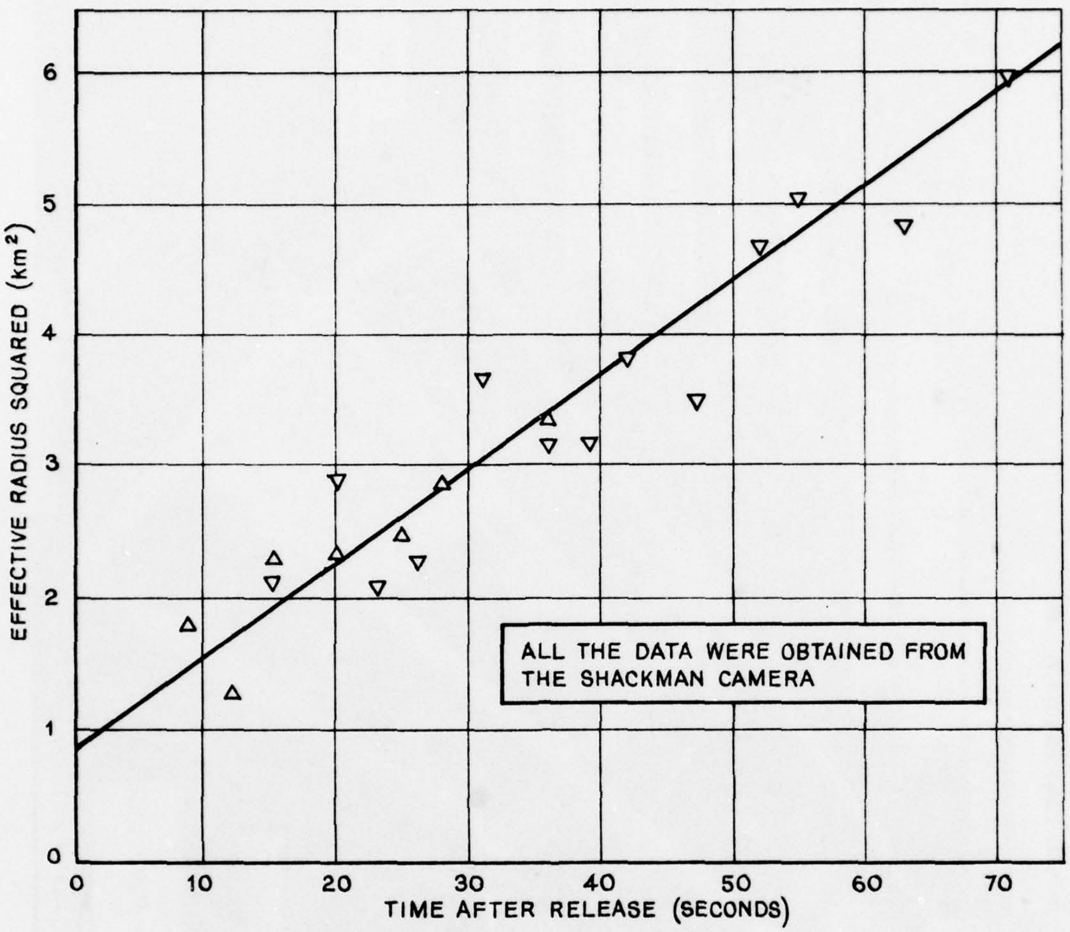


Figure 8. Diffusive growth of grenade cloud

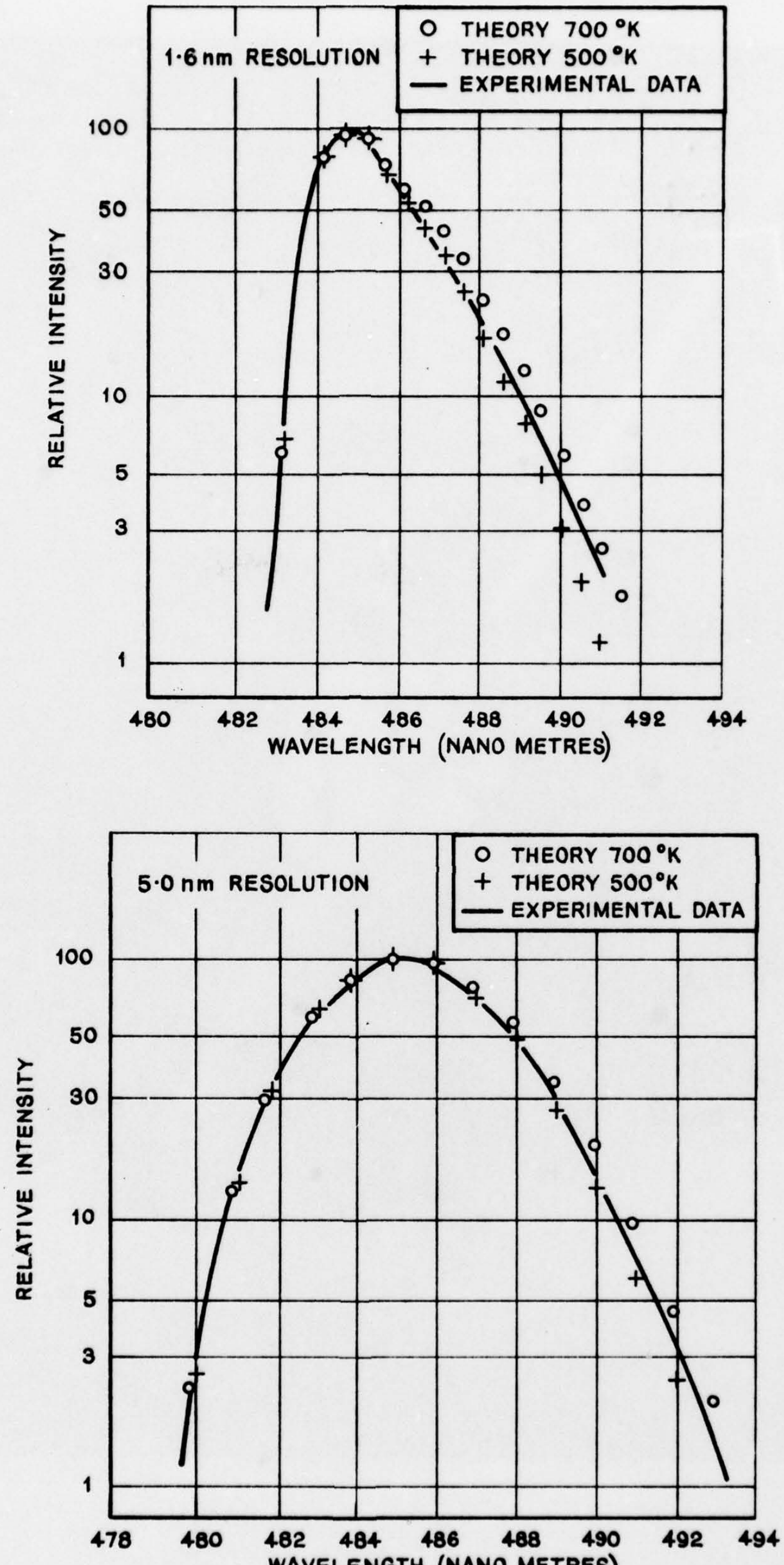


Figure 9. Comparison of observed and theoretical AlO spectra

Figure 10. Kookaburra sounding rocket

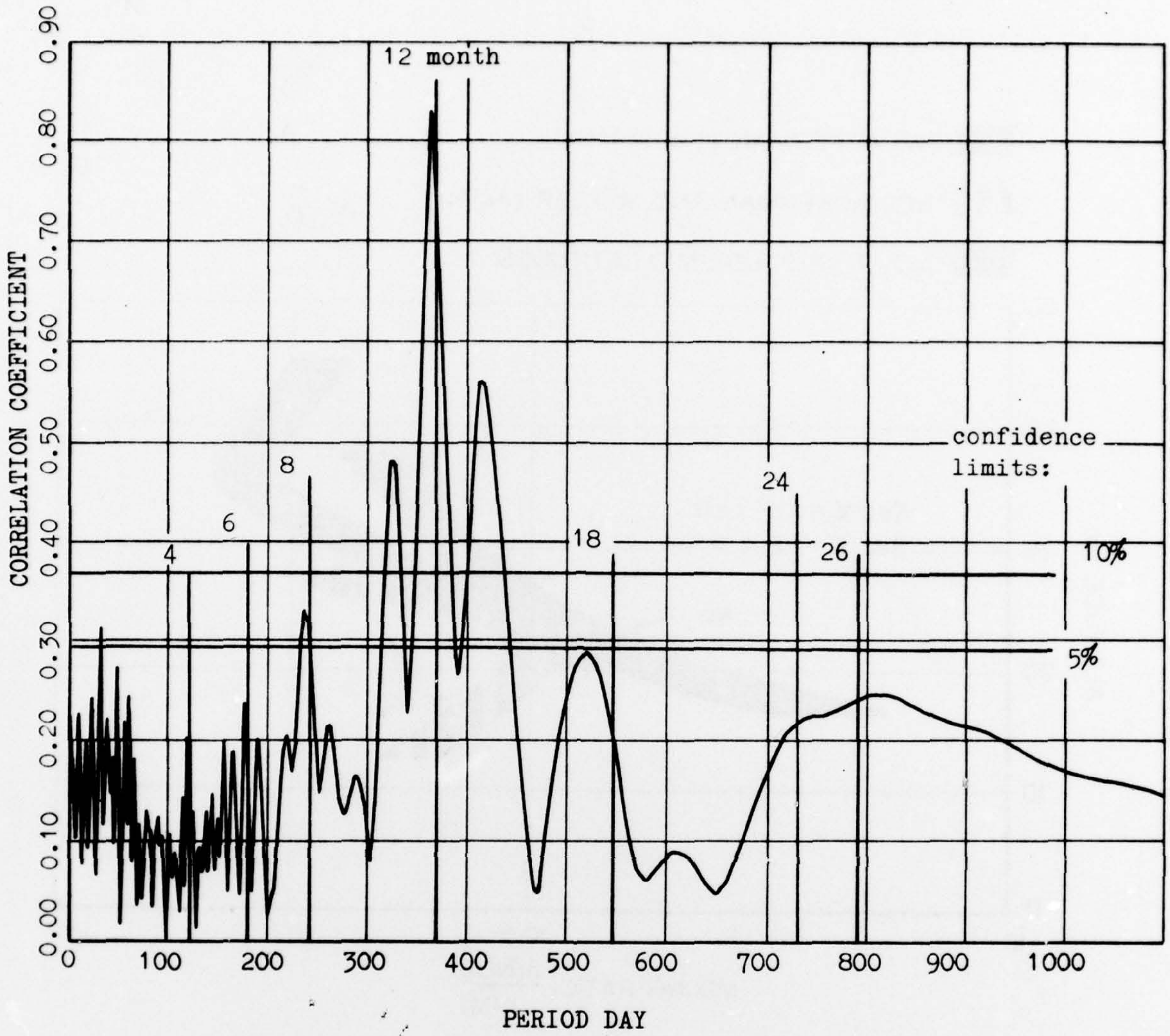


Figure 11. Power spectrum of zonal wind determined from falling sphere data

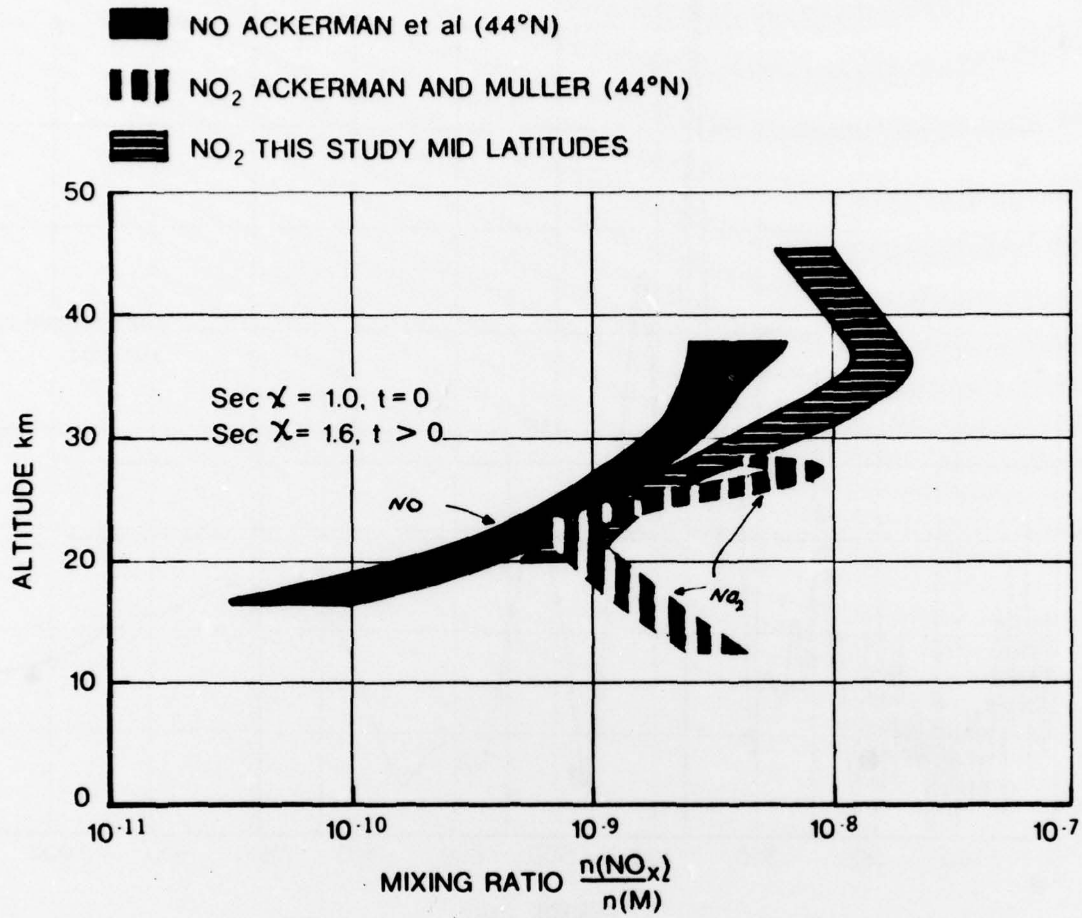


Figure 12. Comparison of measured NO_x with value calculated using observed ozone profile

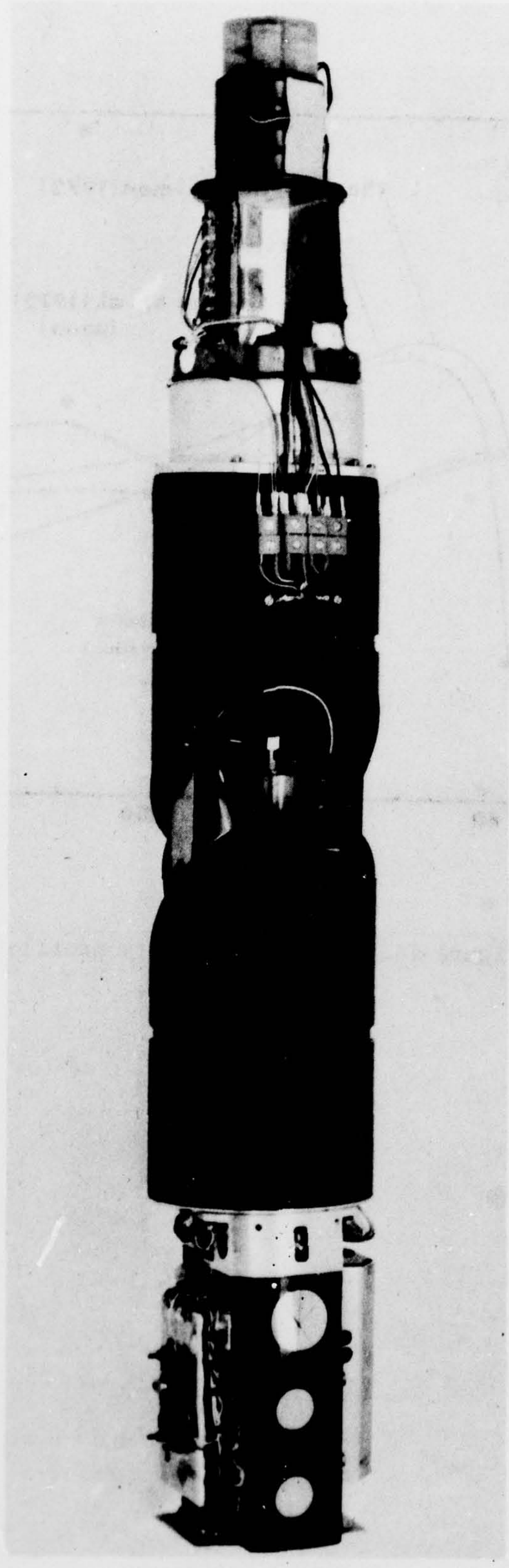


Figure 13. Cockatoo payload containing Lyman alpha telescopes

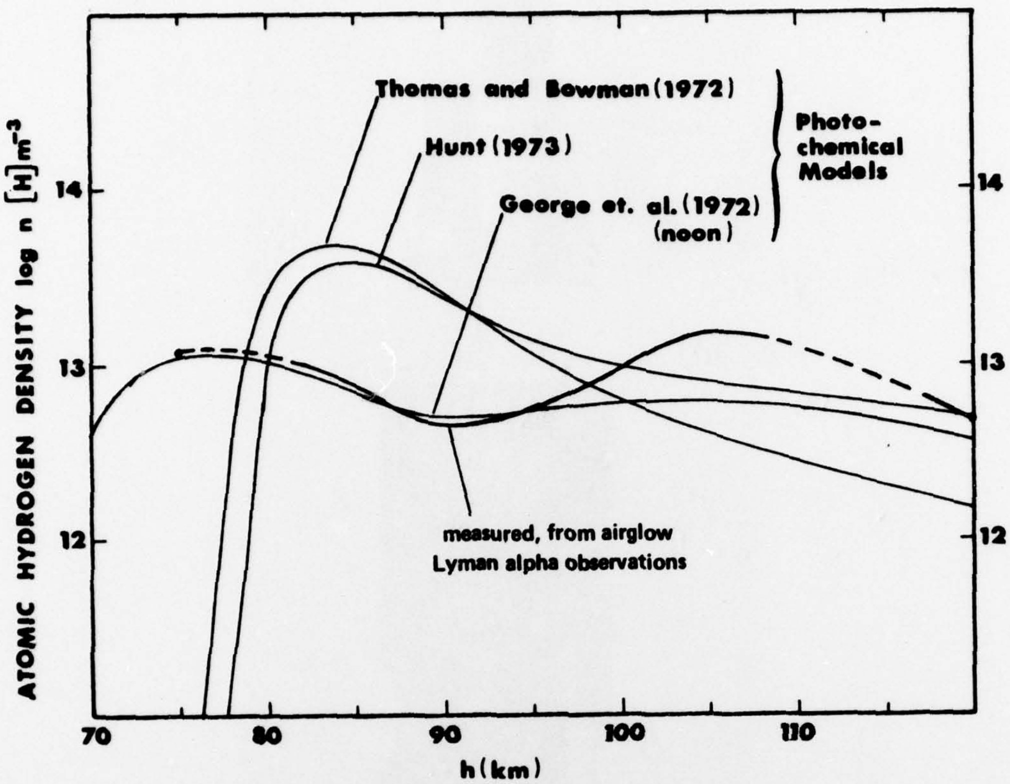
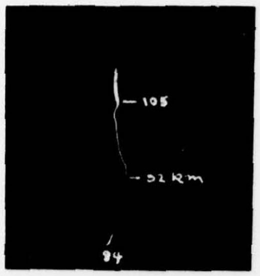


Figure 14. Hydrogen density profiles



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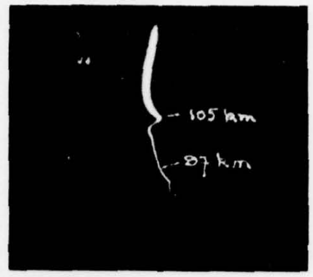

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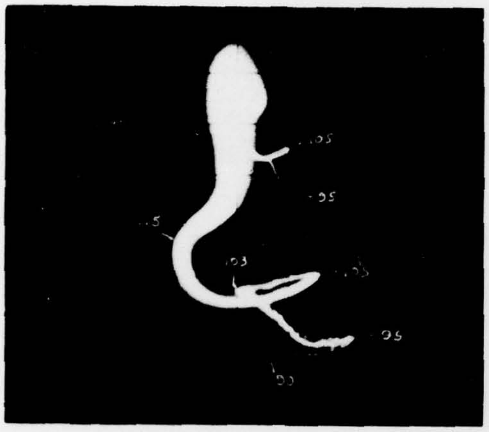

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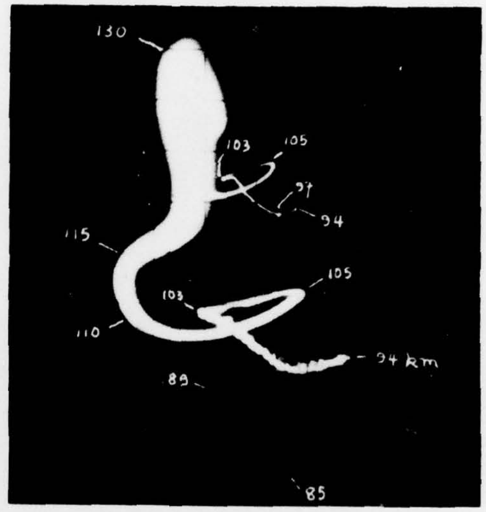

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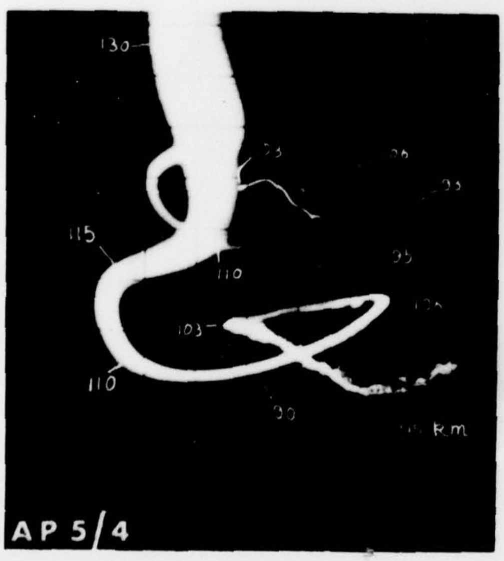

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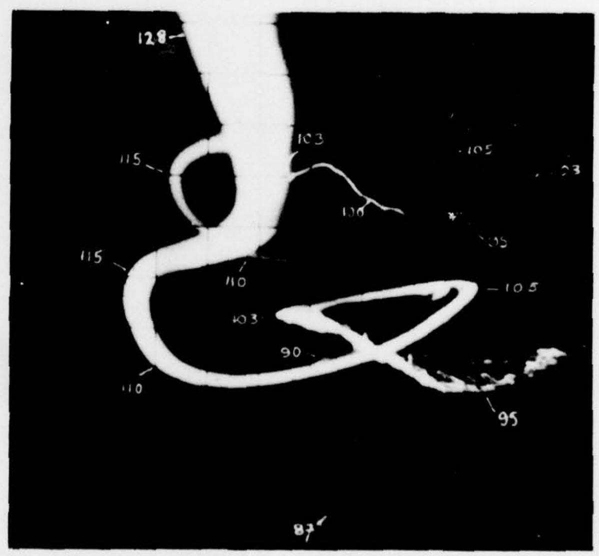

610s

Figure 15. Lithium trail showing turbulence and tides

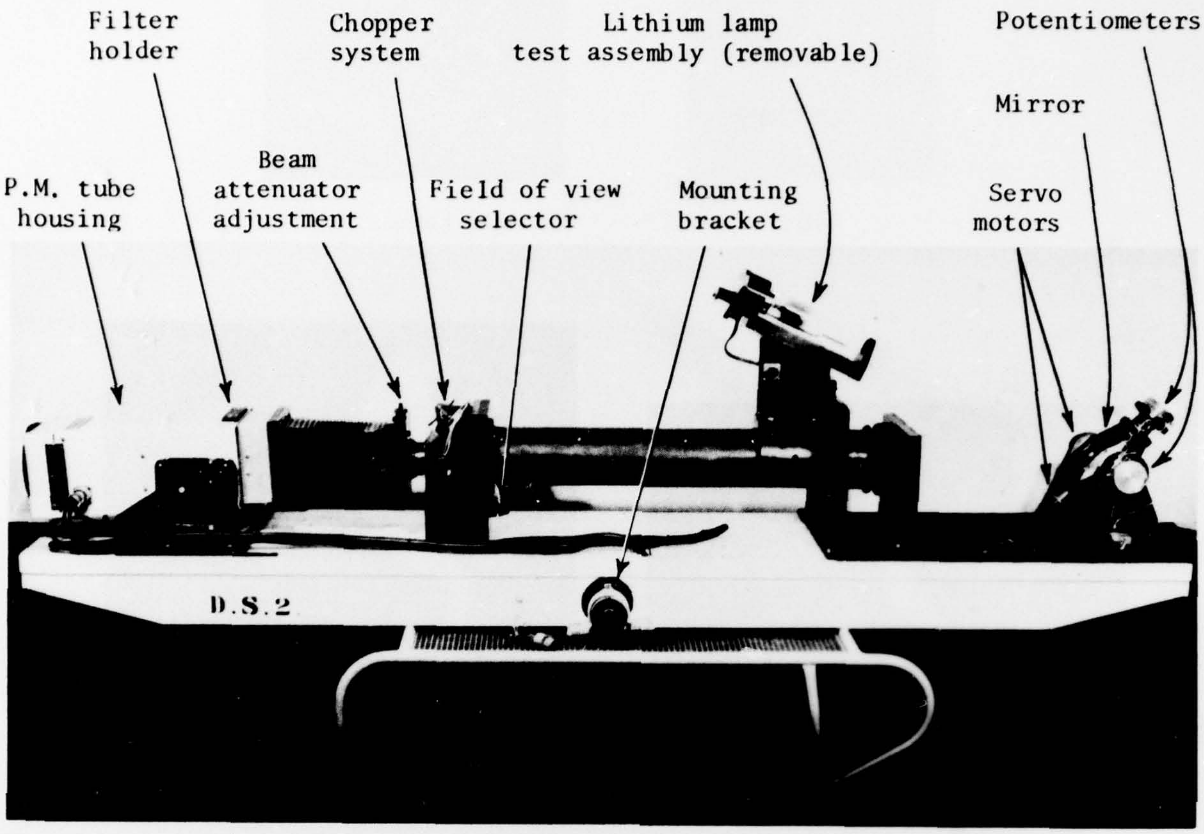

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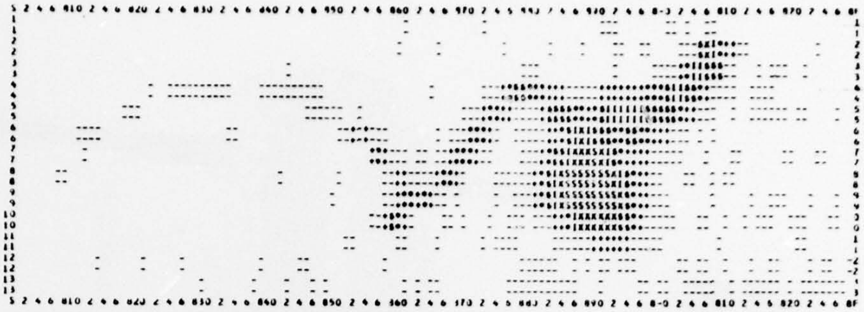
Figure 16. Scanner for detecting lithium trails in daytime



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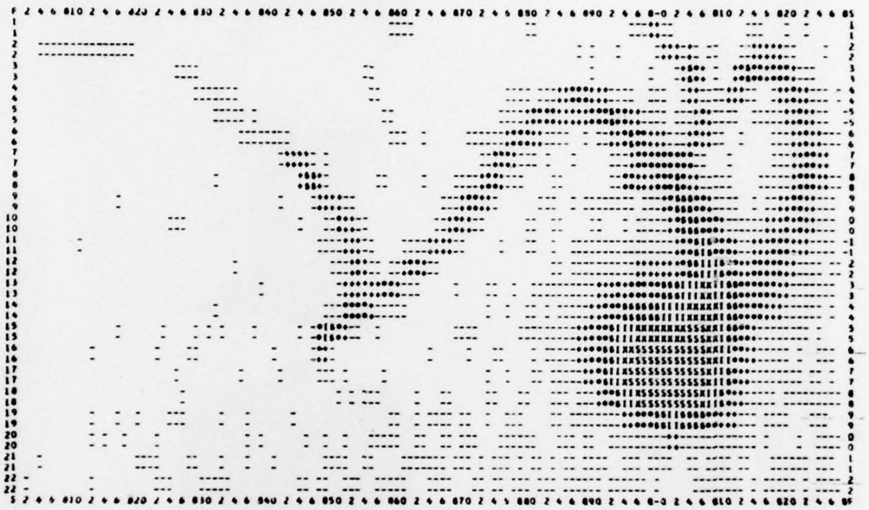

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Figure 17. Development of lithium trail observed by lithium scanner

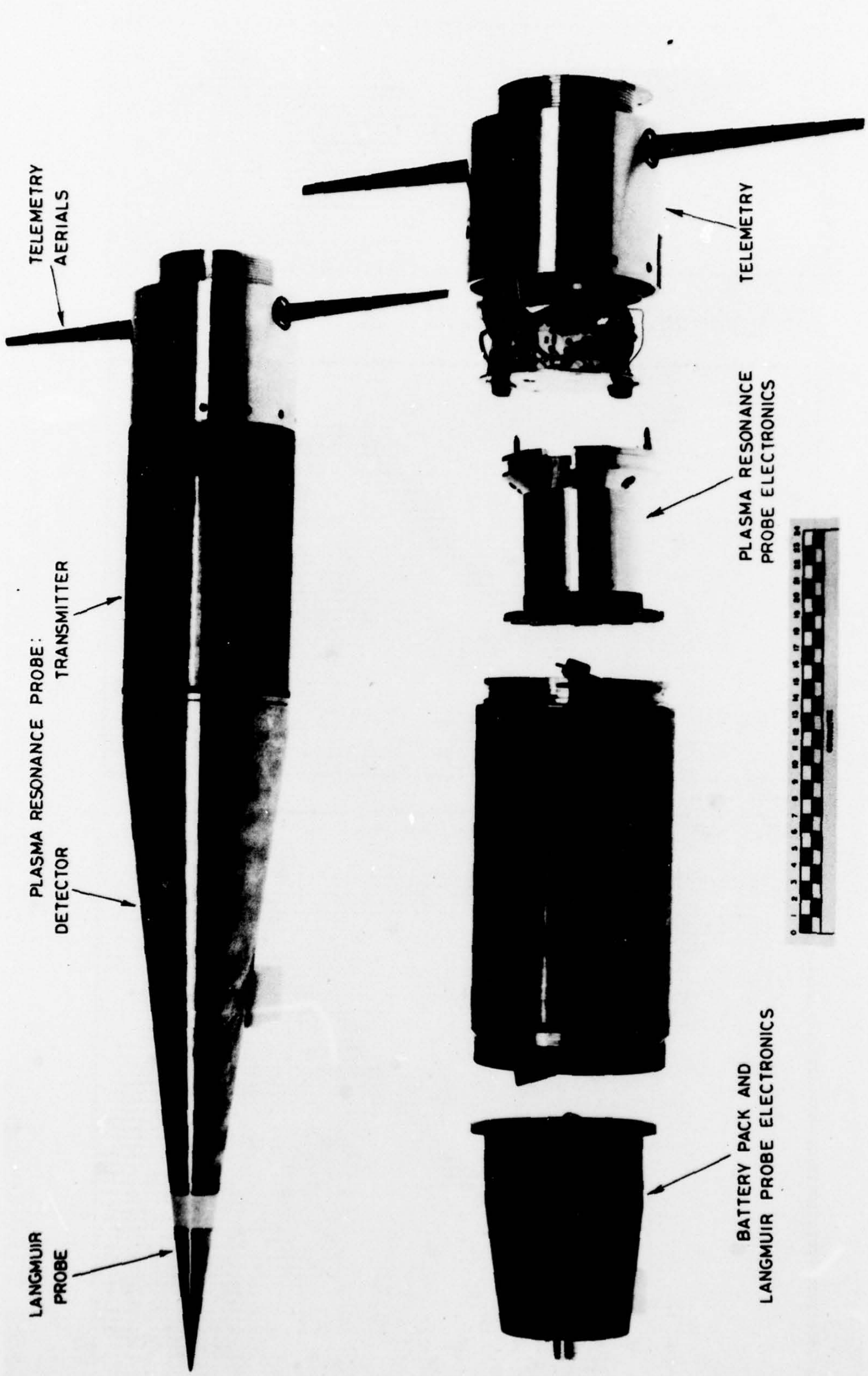

Figure 18. Payload of plasma impedance and Langmuir probe experiments

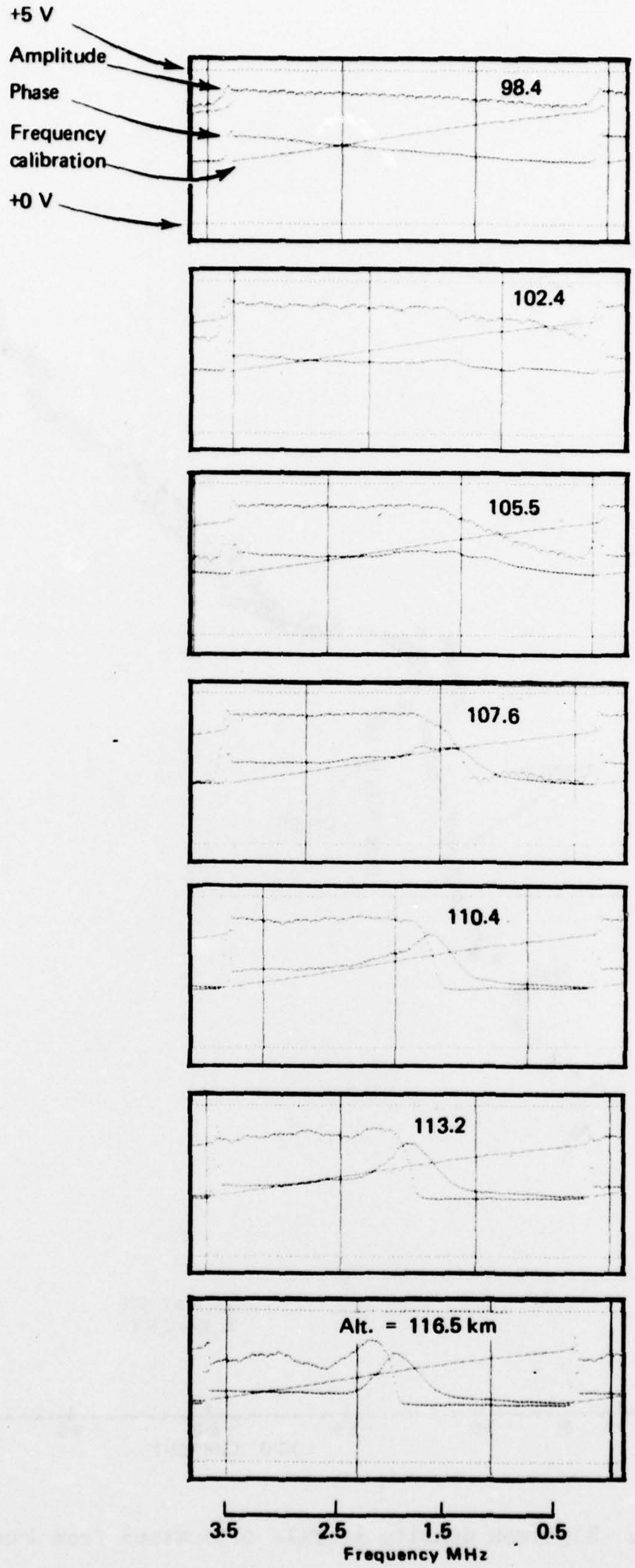

Figure 19. Telemetered data from plasma impedance experiment

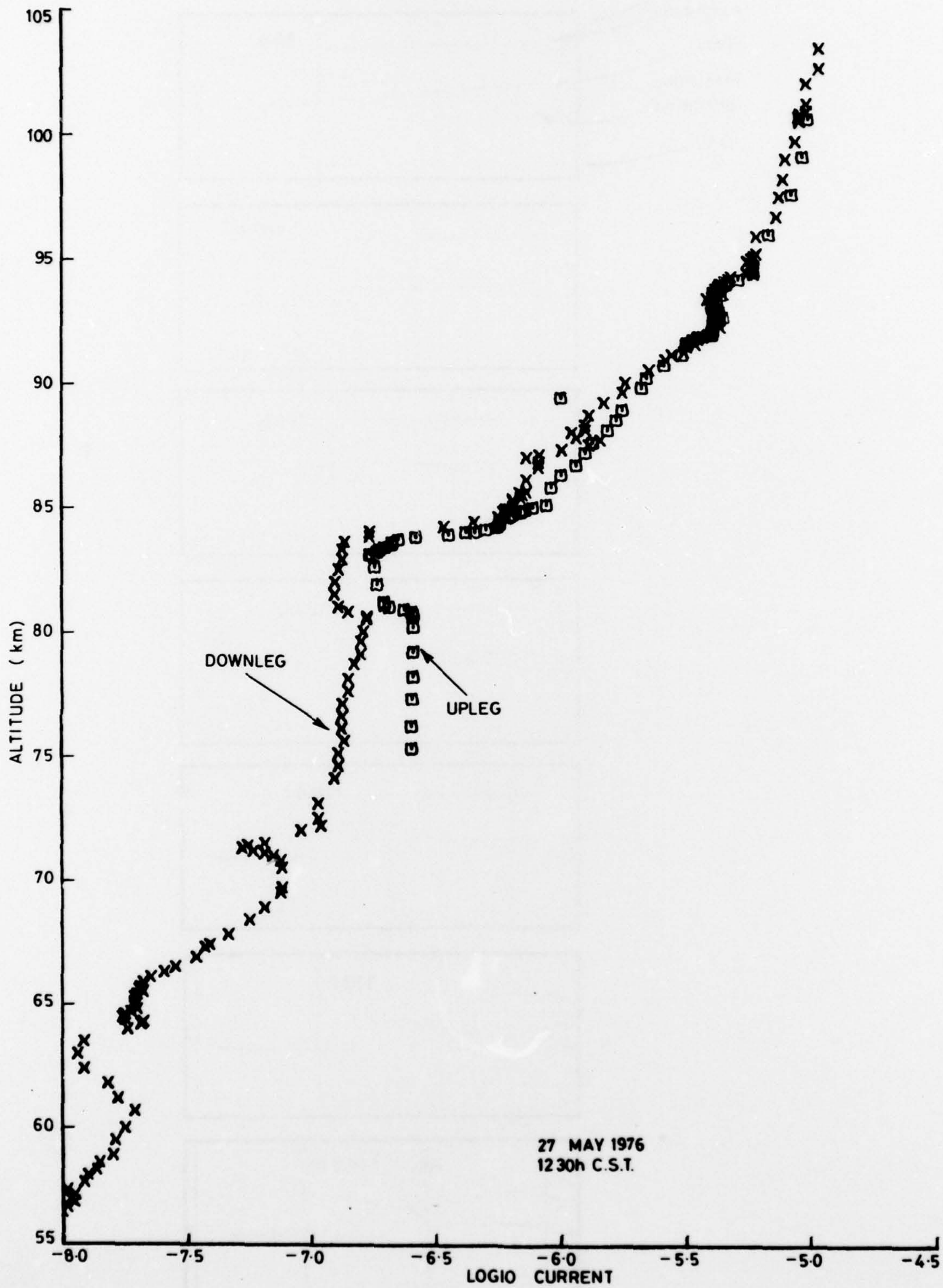

Figure 20. Electron density profile determined from langmuir probe

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Superintendent, Electronics Division	54
Superintendent, Systems Analysis Division	55
Superintendent, Optics and Surveillance Division	56
Superintendent, Workshops and Mechanical Design Division	57
Superintendent, Communications and Electronic Engineering Division	58
Superintendent, Trials Systems Division	59
Head, Ballistics Composite	60
Head, Electronics Composite	61
Head, Surveillance Composite	62
Head, Propulsion Composite	63
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Principal Officer, Aerodynamics Research Group	70
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